Reanalysis of hyperon beta decay data on F/D

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Abstract

We reanalyse hyperon beta decay data to extract the corresponding F and D values. We show that flavour symmetry breaking effects lead naturally to a reduction of the F/D ratio. For proton and neutron our analyses suggests $F/D = 0.49 \pm 0.08$ instead of $F/D = 0.575 \pm 0.016$ which is generally used to analyse the spin data. Our smaller F/D value allows to fullfil the Ellis–Jaffe sum rule implying an unpolarized $s\bar{s}$-sea.

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The original EMC data on the spindependent structure function $g_1(x)$ of the proton [1] has generated great excitement as its analysis suggested that quarks carry only a small fraction of the nucleon spin and that the strange quark sea is substantially polarized in the direction opposite to the nucleon spin. Recent theoretical investigations and improved experimental results [2] have reduced the size of the effect but at the same time have increased the precision such that the statistical significance of e.g. the strange quark polarisation is still about 2 σ. The total spin carried by the quarks is about 40 percent according to these data.

Already at the very beginning it was argued, however, that the validity of the flavour-SU(3) symmetry used in deriving these far reaching conclusions might be questionable [3, 4]. It should be kept in mind that a reduction of the F/D value usually used by just 15 percent would be sufficent to bring the data in agreement with the assumption of an unpolarized strange-quark sea, and flavour-SU(3) violating effects are often of this magnitude. In this contribution we want to sharpen these concerns, arguing that taking flavour-symmetry violation into account tends to reduce the F/D value.

It is well known that semileptonic weak decay data and the spin structure functions of the nucleons test both the axial-vectorial matrix elements. The main difference is that the weak interaction connects different states in the baryon octet, while the structure functions are related to matrix elements which are diagonal in flavour space.

As already noticed earlier [5] in the presence of flavour symmetry breaking it is impossible to disentangle the information on the nucleon and the hyperons without some definite hyperon model. Instead of constructing such a model, we just assume that the mass differences are a measure for the flavour SU(3) symmetry breaking. Thus it is natural to assume that the symmetry breaking effects for F/D are proportional to some dimensionless function of the mass differences. The simplest form for such a function is

$$\delta = \frac{(m_i + m_f) - (m_p + m_n)}{(m_i + m_f) + (m_p + m_n)} \tag{1}$$

with m_i , m_f ,m_p and m_n , denoting the masses of initial hadron, final hadron, proton and neutron. $\delta = 0$ corresponds to the F and D values of proton and neutron (we assume the validity of isopin symmetry). If all baryons in the octet had the same mass δ would be identically zero; introducing the physical masses it just scales with the mass difference between the two states involved and twice the averaged nucleon mass. Table 1 and figure 1 show the F/D ratios from the decays $\Lambda \to$ p; $\sum^- \to$ n; $\Xi^- \to \Lambda$ with the constraint F + D = $g_A/g_V(n \to p) = 1.2573 \pm 0.0028$.

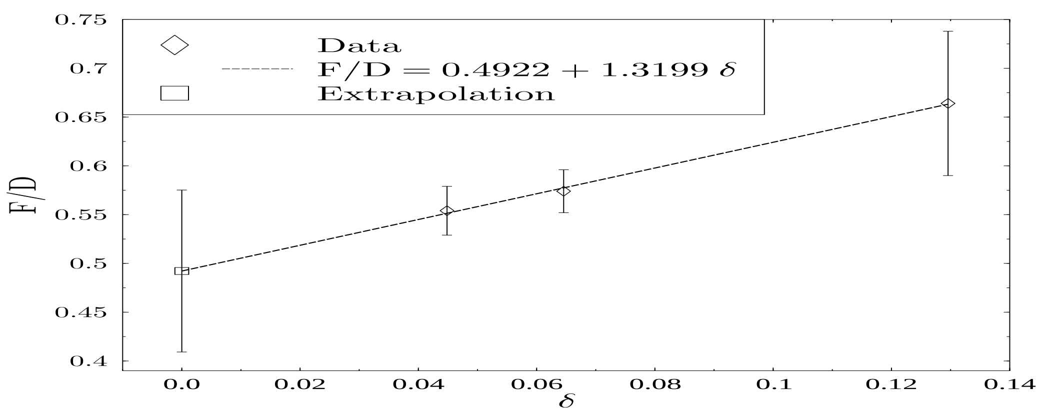

Figure 1: F/D ratios from the decays $\Lambda \to$ p; $\sum^- \to$ n; $\Xi^- \to \Lambda$ with the constraint F + D = $g_A/g_V(n \to p) = 1.2573 \pm 0.0028$.

To get these values we assumed SU(3) symmetry and took g_A/g_V from [6].

decay	F/D	δ	$g_A/g_V = \ldots$
n $\to$ p	0.492 $\pm$0.083	0	$1.2573 \pm 0.0028 = F + D$
$\Lambda \to$ p	0.554 $\pm$0.025	$4.485 \cdot 10^{-2}$	$0.715 \pm 0.015 = F + D/3$
$\sum^- \to$ n	0.574 $\pm$0.022	$6.457 \cdot 10^{-2}$	$-0.340 \pm 0.017 = F - D$
$\Xi^- \to \Lambda$	0.664 $\pm$0.074	$1.296 \cdot 10^{-1}$	$0.25 \pm 0.05 = F - D/3$

Table 1.

Also shown is the extrapolation to $\delta = 0$, which corresponds to the F/D ratio for proton and neutron, with $F/D = 0.49 \pm 0.08$. To obtain this extrapolation (and the corresponding errors) we assumed a linear correlation between F/D and δ, which is certainly justified as long as δ is small.

The precise value of F/D extrapolated to the nucleon states depends somewhat on the definition of δ. If the denominator would be substituted e.g. by some constant mass $M = m_p + m_n$ the result is $F/D = 0.50 \pm 0.08$ but it should be obvious from figure 1 that in any case one can get a value substantially reduced with respect to that of previous data analysises [7, 5]. To summarize, the two main effects of the assumed correlation are:

1.) The error for $\mathrm{F/D_{proton}}$ is much larger than just the weighted average of the measurements.

2.) Data seem to indicate a positive correlation between δ and F/D. This results in a $\mathrm{F/D_{proton}}$ ratio substantially smaller than the average of all measurements.

Let us discuss next the consequences of these results for the polarized structure functions. The Bjorken sum rule [8], which is a rock-solid prediction of QCD, is unaffected by our data analysis. The Ellis–Jaffe sum rule [9], which is not related to any fundamental symmetry, is, however, strongly affected .

With the original Ellis–Jaffe asumption $\Delta s = 0$ one gets ($I_p(Q^2) = \int_0^1 dx g_1^p(x, Q^2)$ etc.):

$$I_p(Q^2) = \frac{3F + D}{18} C_{NS}(Q^2) + \frac{3F - D}{9} C_S(Q^2) - 0.018 \frac{GeV^2}{Q^2} \tag{2}$$

$$I_n(Q^2) = -\frac{D}{9} C_{NS}(Q^2) + \frac{3F - D}{9} C_S(Q^2) \tag{3}$$

$$I_d(Q^2) = \frac{3F - D}{36} C_{NS}(Q^2) + \frac{3F - D}{9} C_S(Q^2) - 0.009 \frac{GeV^2}{Q^2} \tag{4}$$

with the Q^2 dependence of [10]:

$$C_{NS}(Q^2) = 1 - \frac{\alpha_s(Q^2)}{\pi} - 3.5833 \left(\frac{\alpha_s(Q^2)}{\pi}\right)^2 - 20.2153 \left(\frac{\alpha_s(Q^2)}{\pi}\right)^3 \tag{5}$$

$$C_S(Q^2) = 1 - \frac{\alpha_s(Q^2)}{3\pi} - 0.5496 \left(\frac{\alpha_s(Q^2)}{\pi}\right)^2 \tag{6}$$

The higher twist contribution in equations (2) - (4) is based on the QCD sum rule estimates [15, 16], the explicit form used here can be found in [17]. Table 2 shows the resulting values with $\alpha_s(Q^2)$ from [6] and the corresponding experimental data (lower row).

$\mathrm{I}_p(Q^2 = 3\ \mathrm{GeV}^2)$	$\mathrm{I}_p(Q^2 = 10\ \mathrm{GeV}^2)$	$\mathrm{I}_n(Q^2 = 2\ \mathrm{GeV}^2)$	$\mathrm{I}_d(Q^2 = 4.6\ \mathrm{GeV}^2)$
0.134 ± 0.025	0.145 ± 0.025	-0.034 ± 0.025	0.051 ± 0.025
$0.129 \pm 0.004 \pm 0.009$ ref. [11]	$0.136 \pm 0.011 \pm 0.011$ ref. [12]	-0.022 ± 0.011 ref. [13]	$0.023 \pm 0.020 \pm 0.015$ ref. [14]

Table 2.

The nice agreement between the Ellis–Jaffe predictions and the various experiments leads us to the following statement: From the experimental data one can either conclude that the (strange) sea is strongly polarized (and flavour SU(3) is perfect), which is the standard conclusion, or that the flavour SU(3) is slightly broken and the sea is unpolarized. Since the second conclusion is much less spectacular it appears to us as more probable. In [18] we showed, that it is in fact possible to fit the Bjorken x dependent polarized structure functions without sea polarization for a phenomenological model which includes explicite flavour SU(3) breaking. Thus we conclude that from the present data on polarized structure functions one cannot derive that the strange quark sea is strongly negatively polarized.

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Figure Caption

Figure 1: F/D ratios from the decays $\Lambda \rightarrow$ p; $\sum^{-} \rightarrow$ n; $\Xi^{-} \rightarrow \Lambda$ with the constraint F + D = $g_A/g_V(n \rightarrow p) = 1.2573 \pm 0.0028$.